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The effect of stimulus element redundancy on speed of discrimination as a function of state and process limitation

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The effect of spatially repeated stimulus elements on the speed of discrimination, measured in a sorting task, was determined under conditions of low stimulus visibility (state limitation) and high stimulus similarity (process limitation). A significant increase in speed of sorting stimuli was found when the stimuli were state limited but not when process limited, even though base speeds were the same in both cases. It is concluded that element redundancy will improve discrimination performance only when the need for the improvement is a state limitation.

In research on perceptual discrimination, two different performance measures are commonly used to measure difficulty of discrimination: accuracy and speed. Either measure is assumed to be at least monotonically related to discrimination difficulty. Unfortunately, however, each of these measures has a limited capability in demonstrating changes in discriminability. Any measure of accuracy cannot exceed 100% correct discriminations, and thus increases in discriminability cannot be reflected by improvements in accuracy if discriminability is too great. While speed of discrimination will frequently be able to reflect changes in discriminability at still higher levels, even this measure becomes insensitive to differences if discriminability is great enough. (See Garner, 1969.) Because of these limitations, experiments concerned with demonstrating the effect of stimulus factors on discriminability must be sure to establish a level of performance sufficiently low so that measurable improvement can occur. There must, in other words, be some demonstrable need for improvement in discrimination before improvement can be found experimentally.

Element Redundancy

The present research is concerned with the role of redundancy in improving visual discrimination. One of the most straightforward methods of introducing stimulus redundancy is the simple repetition of stimulus elements within a stimulus array.

Stimulus element redundancy has been shown to result in an improvement in discrimination accuracy in tachistoscopic visual-recognition tasks involving the recognition of letters presented at low contrast for very brief durations (Eriksen & Lappin, 1965; Garner & Flowers, 1969). On the other hand, Morton (1969) demonstrated that the simple repetition of discrete stimulus elements (numerals) on each stimulus card did not increase the speed of classification in a card-sorting task. In each case the evidence for improvement or its lack was quite unequivocal. These contradictory results might therefore suggest that stimulus-element redundancy is an effective means of improving accuracy of stimulus identification but provides little or no gain in the speed of discrimination. However, Keeley & Doherty (1968) also failed to find an improvement in discrimination accuracy with the simultaneous multiple presentation of Landolt rings in a stimulus. Thus, an interpretation of these discrepant results in terms of methodological differences is clearly not adequate.

State and Process Limitation

An alternative explanation of the discrepant results is suggested by the nature of the stimuli themselves. The stimuli used by both Eriksen & Lappin (1965) and by Garner & Flowers (1969) were presented tachistoscopically at low contrasts for very brief durations. In these cases the primary limitation on accuracy of identification was low stimulus visibility rather than difficulty of discriminating the alternative stimuli themselves. Garner (1970) has described such tasks, in which stimulus visibility is the primary limiting factor, as *state limited.*

In contrast, the stimuli used by Morton (1969) were numerals that were in high contrast to the white cards on which they were presented. Thus, visibility of the stimuli did not contribute to perceptual difficulty. In the experiment by Keeley & Doherty (1968), the stimuli were tachistoscopically presented, but at moderate durations. Certainly it is possible that the primary discrimination factor operating with Landolt rings, differing only in location of a single gap, is not difficulty in seeing the ring, but in distinguishing one ring from another. Such tasks, in which level of performance is determined by the similarity of the stimulus alternatives rather than by the sufficiency of the stimulus energy encountered at the peripheral level, have been described by Garner (1970) as *process limited.*

It is possible, therefore, that stimulus-element redundancy is effective in improving the performance of a visual discrimination task that is primarily state limited, but provides little or no facilitation of such a task if it is primarily process limited. So far, however, there has been no explicit experimental test of this idea.

Purpose

The purpose of the present experiment is to measure speed of discrimination for stimuli that can be presumed to provide either state or process limitation and to determine for equivalent levels of performance whether element redundancy improves discrimination with state-limited stimuli but not with process-limited stimuli.

METHOD

Stimulus Materials

Each stimulus consisted of one or two dots on a white card, 8.9 x 6.3 cm, with the longer side vertical and a small piece cut off the upper left corner to maintain proper orientation. On a single trial, S was required to sort a deck of 36 such cards. In each deck there were just two different classification alternatives, "right" or "left," based upon the horizontal location of either the single dot or the pair of dots. Each of six decks of 36 cards used in this experiment represented one experimental condition determined by the particular combination of levels of the experimental variables described below.

Procedure

Subjects. Ss were 15 male college students, volunteers who were paid $3.00 for participation. All conditions were run in a single session which lasted about 2 h.

Task. Each S was required to hold the deck of cards in one hand and to deal them off into two piles. He was instructed to separate the cards with the dot(s) on the right from the cards with the dot(s) on the left, "as rapidly as possible without making mistakes." Each S was allowed to scan through each deck before sorting, to make sure he understood the discrimination required. Each trial was begun with the spoken signal, "Ready, set, go!" Trials

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were timed with a stopwatch. Sorting time and number of errors committed were recorded following every trial. Ss were given feedback of both sorting time and errors following each trial.

Order of presentation. Each S was run on seven blocks of six trials. Each block included a single trial on each of the six different decks. Order of presentation within each block was determined by a 6 by 6 Latin square. The first three blocks of trials were used to familiarize S with the task in order to stabilize performance; only the data from the last four blocks were used for analysis. Analysis of variance indicated a slight learning effect throughout these last four blocks; however, this effect did not interact with any other observed effect, and no data concerning the learning effect will be presented.

Experimental Variables

Color, B(lack) or Y(ellow). For Level B, one or two black dots were located on each stimulus card. For Level Y, one or two (Munsell 10Y 9/4) yellow dots were located on each card. The black dots were very easy to discriminate from the white background of the stimulus cards, while the yellow dots were light and quite difficult to discriminate from the background. Thus, the two levels of color, B and Y, may be assumed to provide two levels of *state limitation.*

Horizontal separation, L(arge) or S(mall). For Level L, each stimulus card contained one or two dots located 0.35 cm either to the right or to the left of an imaginary vertical line passing through the center of the card. Thus, the "right" and "left" alternatives were separated by 0.70 cm. For Level S, the horizontal separation of alternatives was reduced to 0.40 cm, with the stimulus element(s) located 0.20 cm to the right or left of the imaginary vertical axis. Since Level S produces a more difficult task than Level L due to greater similarity of the classification alternatives, it may be assumed that the manipulation of horizontal separation provides two levels of *process limitation.*

Number of elements (1 or 2). For Level 1, each stimulus card contained a single dot. For Level 2, a pair of dots was located on each card. Thus, Levels 1 and 2 represent two levels of *element redundancy.*

For Level 1, each dot was located at one of three vertical levels--2.5, 3.75, or 5.0 cm from the top edge of the card. For Level 2, three vertical configurations of the pair of dots were used--2.5 and 3.75 cm, 3.75 and 5.0 cm, 2.5 and 5.0 cm from the top edge of the card. Within a deck each of the three possible vertical configurations appeared equally often. Vertical position uncertainty was used as a control procedure to prevent fixation upon a narrow region of each card (see Eriksen & Lappin, 1965). Ss were told that the vertical position of the dots was a control procedure and was unrelated to the classification of stimuli, which was to be done on the basis of *horizontal* position.

Table 1
Mean Sorting Times (Seconds) for Each Condition

S	BL1	BL2	BS1	BS2	YL1	YL2
1	23.20*	24.20	28.98	27.95	31.33	29.13
2	23.20	23.28	27.58	26.43	28.92	25.78
3	18.53	17.73	20.75	22.40	21.65	19.50
4	17.18	18.10	22.50	22.30	21.70	20.70
5	27.28	23.60	32.38	31.88	30.28	27.30
6	24.93	24.30	28.95	29.95	29.50	29.18
7	19.68	18.80	23.03	20.98	23.38	22.25
8	25.28	25.93	30.08	28.88	28.68	26.30
9	22.55	21.45	26.23	24.85	27.23	28.23
10	22.23	22.75	23.83	24.97	25.05	24.00
11	22.40	23.00	28.40	28.60	28.63	27.78
12	18.20	18.12	20.75	19.23	22.15	18.80
13	20.70	20.88	24.70	23.68	23.68	23.40
14	16.82	15.95	19.03	19.30	20.45	19.08
15	16.98	16.70	17.98	18.13	20.95	19.45
Average	21.28	20.99	25.01	24.64	25.57	24.06

**Each cell entry is the mean of four sortings of decks of 36 cards each.*

Experimental Conditions

Complete crossing of each of the levels of each of the experimental variables described above would yield eight different experimental conditions. Pilot data indicated that the combination of small horizontal separation and yellow dot color (YS1 and YS2) produced tasks of such difficulty that consistent accurate sorting was impossible. The remaining six combinations of variables (BL1, BL2, BS1, BS2, YL1, YL2) provided the conditions used in the experiment.

RESULTS

Sorting Times

The mean sorting times per deck, based upon four experimental trials per S, are presented in Table 1.

State and process limitations. A base level of performance (21.28 sec) is provided by Condition BL1, with highly visible dots and easily discriminable locations. Condition BS1 increased sorting time to 25.01 sec by making the spatial discrimination more difficult (process limitation). Condition YL1 increased sorting time to 25.57 sec by making the dots more difficult to see (state limitation). While these performance decrements of about 4 sec, produced by the independent manipulations of state and process limitations, were shown by analysis of variance to be highly significant ($p < .01$), the sorting times of the BS1 and YL1 conditions themselves did not differ significantly ($F < 1$). Thus, the BS1 condition and the YL1 condition provide performance which can be improved; furthermore, the opportunity for improvement in each case is approximately equal.

Element redundancy. A measure of the redundancy effects may be obtained by subtracting the mean sorting time of each two-dot condition from the time for the corresponding one-dot condition (BL1 – BL2, BS1 – BS2, YL1 – YL2). The pair (BL1 – BL2) provided a control comparison, since little improvement in performance due to element redundancy was expected by duplicating elements already highly visible and easily discriminable. The improvement in performance was 0.29 sec, and this change was not significantly different from zero ($F < 1$). The lack of significance of this improvement is emphasized by the fact that only eight of the 15 Ss showed improvement at all.

The pair (BS1 – BS2) concerns the effect of element redundancy when the visual discrimination task is process limited, and the improvement in sorting speed in this case was 0.37 sec. This difference is not significantly different from zero ($F < 1$), and this lack of significance is again emphasized by the fact that only 9 of the 15 Ss sorted the redundant deck more rapidly. The present data therefore add to the evidence that multiple-element redundancy is of little use in improving performance in a visual discrimination task that is process limited.

The redundancy gain observed in the state-limited pair (YL1 – YL2) was 1.51 sec, and this gain was significant ($p < .025$). Fourteen of the 15 Ss sorted the redundant condition more rapidly than the nonredundant condition. Thus both parametric and nonparametric analyses demonstrate that stimulus-element redundancy produced a substantial improvement in the performance of a state-limited visual task.

Table 2
Mean Number of Errors Per Trial

BL1	BL2	BS1	BS2	YL1	YL2
.200*	.100	.667	.517	.300	.250

**Each cell entry is the mean number of errors per trial of 36 stimuli, averaged across four trials and 15 Ss.*

Error Rates

The mean number of errors per deck for each condition is shown in Table 2. Errors were so infrequent that detailed quantitative analysis of these data would be difficult to interpret. The slightly higher error rates observed in the process-limited conditions indicate that these conditions may have actually been slightly more difficult than the state-limited conditions. Since the process-limited condition is the one that showed no improvement with the addition of element redundancy, however, there is nothing in these error data to suggest that the results obtained with time measures are artifactual.

DISCUSSION

The results of the present study suggest that two important conditions must be met in order for stimulus-element redundancy to be an effective means of improving discrimination performance. First, the difficulty of the task must be great enough so that there exists room for an improvement in performance. Secondly, the source of this task difficulty must stem from state limitations rather than from process limitations.

Element and Dimensional Redundancy

The results of the present study by no means suggest that forms of stimulus redundancy other than element redundancy cannot be used to improve the performance of a process-limited discrimination task. Another form of stimulus redundancy, which has been shown to be an effective means of facilitating discrimination tasks which are process limited, is dimensional redundancy. Dimensional redundancy has been shown to improve discrimination performance of tasks which may be presumed to have been process limited, as measured by absolute judgment (Eriksen & Hake, 1955; Lockhead, 1966), card-sorting speed (Garner, 1969; Garner & Felfoldy, 1970), and discrete reaction time (Biederman & Checkosky, 1970), when the dimensions can be integrated into an effectively new dimension.

State vs Process Models of Discrimination

The finding of the present study, that stimulus-element redundancy produces a performance gain only in a visual discrimination task which is state limited, strongly emphasizes the need to distinguish between state and process limitations as sources of task difficulty. More specifically, the present data suggest that it may be highly inappropriate and misleading to describe the effects of redundancy in state- and process-limited tasks by means of the same perceptual models.

For example, Eriksen and Lappin (1965) used a multistate model to provide an excellent prediction of the multiple-element-redundancy gain they obtained from a state-limited visual recognition task. Multistate models are a particular class of models that seem highly appropriate in describing a multiple-element-redundancy gain in a state-limited task, since such models imply that element redundancy provides multiple opportunities for sufficient stimulus energy to be detected by the observer. On the other hand, models that postulate the integration of stimulus *information* (such as information-theory models) may be far more suitable for interpreting other forms of redundancy gains observed in process-limited discrimination tasks.

REFERENCES

BIEDERMAN, I., & CHECKOSKY, S. F. Processing redundant information. Journal of Experimental Psychology, 1970, 83, 486-490.

ERIKSEN, C. W., & HAKE, H. W. Multidimensional stimulus differences and accuracy of discrimination. Journal of Experimental Psychology, 1955, 50, 153-160.

ERIKSEN, C. W., & LAPPIN, J. S. Internal perceptual system noise and redundancy in simultaneous inputs in form identification. Psychonomic Science, 1965, 2, 351-352.

GARNER, W. R. Speed of discrimination with redundant stimulus attributes. Perception & Psychophysics, 1969, 6, 221-224.

GARNER, W. R. The stimulus in information processing. American Psychologist, 1970, 25, 350-358.

GARNER, W. R., & FELFOLDY, G. L. Integrality of stimulus dimensions in various types of information processing. Cognitive Psychology, 1970, 1, in press.

GARNER, W. R., & FLOWERS, J. H. The effect of redundant stimulus elements on visual discrimination as a function of element heterogeneity, equal discriminability, and position uncertainty. Perception & Psychophysics, 1969, 6, 216-220.

KEELEY, S. M., & DOHERTY, M. E. Simultaneous and successive presentations of single-featured and multi-featured visual forms: Implications for the parallel processing hypothesis. Perception & Psychophysics, 1968, 4, 296-298.

LOCKHEAD, G. R. Effects of dimensional redundancy on visual discrimination. Journal of Experimental Psychology, 1966, 72, 95-104.

MORTON, J. The use of correlated stimulus information in card sorting. Perception & Psychophysics, 1969, 5, 374-376.

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